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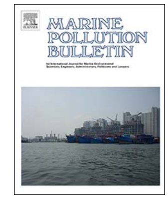

Benefits and shortcomings in the employment of non-destructive benthic imagery for monitoring of hard-bottom habitats

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ABSTRACT

Hard-bottom habitats with complex topography and fragile epibenthic communities are still not adequately integrated in benthic monitoring programs as demanded by their potential ecosystem importance. While status indicators are defined by major EU directives, methods commonly used to provide measures are deficient in quantification of biota on hard surfaces. We address suitability of recent advancements in seafloor imaging to support monitoring activities. Comparative evaluation of the performance of high-resolution imagery and physical sampling (grab, dredge, SCUBA-diving) to detect taxonomic and functional components of epibenthos revealed that (1) with minimal habitat disturbance on large spatial scales imagery provides valuable cost-efficient assessment of complementary metrics of rocky reef habitats features and community structure, (2) despite poor taxonomic resolution image-derived data for habitat-forming taxa might be sufficient to infer richness of small sessile and mobile fauna, (3) physical collection is irreplaceable for robust record of species-richness to establish baselines and monitor changes on species level.

1. Introduction

Marine coastal ecosystems contend with a wide range of anthropogenic pressures such as physical engineering, physical and chemical pollution and the introduction of invasive species (Bates et al., 2007; de Jonge et al., 2006; Gray, 1997; Jenkins, 2003). Particularly benthic invertebrate communities are affected since many taxa are sedentary or sessile and cannot avoid disturbances (Solan et al., 2004). While preventing the loss of seafloor habitats and thereby maintaining ecosystem services and benefits must be the final goal (Elliott, 2011), monitoring helps to assess the various effects on seabed biota, and maybe more importantly, assists in the understanding of the general ecological functioning (Barrio Froján et al., 2016). In recent years, great progress had been made in standardizing benthic environmental monitoring at national, regional and international level, principal in reaction to increasing human seafloor activities (Jørgensen et al., 2011). However, since soft sediments present the predominant substrata in most temperate coastal waters, monitoring is often restricted to endofaunal sampling and data rarely covers total benthic diversity (Buhl-Mortensen et al., 2014). In the German Baltic Sea, like in other European seas, sublittoral hard substrata and their associated epibenthic assemblages are by now not as adequately integrated in marine benthic monitoring programs as required by their potential ecological importance. Due to a complex topography and often high structural heterogeneity such as those formed by cobble and boulder fields, hard-bottom communities are characterized by a smaller-scale spatial variability than the surrounding sand or mud flats (Rees, 2009; Witman and Dayton, 2001). Habitat-forming organisms such as kelp or sponges create the biogenic relief of the hard substrata and further increase the structural complexity of the habitat, supporting diverse associated epifauna (Bradshaw et al., 2003; Sheehan et al., 2013; Witman and Dayton, 2001). Overall, hard-bottom communities constitute a considerable proportion of marine biodiversity (Rees, 2009), significantly contribute to benthic production and provide irreplaceable ecosystem services (Wahl, 2009). They play major role for nutrient cycling, water purification, and benthic-pelagic coupling (Sheehan et al., 2013; Wahl, 2009), alter patterns of fluid transport (Eckman et al., 1989; Rosman et al., 2007) and particulate fluxes (Duggins, 1990; Eckman and Duggins, 1991), provide refuge from currents or predation for juvenile invertebrates (Bradshaw et al., 2003; Pirtle et al., 2012; Smale et al., 2013) and serve as a nursery for demersal fish species, many of which are commercially important (Smale et al., 2013).

In Europe, two major directives focus on conservation and sustainable use of marine resources in the exclusive economic zone (EEZ), thereby defining conservation needs for benthic habitats and their associated communities. Habitats Directive (HD, 92/43/EEC; Commission, 1992) and Marine Strategy Framework Directive (MSFD, 2008/56/EC; Commission, 2008) demand special assessment efforts on

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hard-bottom habitats (rock and boulders, HD: 1170 “reefs”) including specific monitoring programs capturing the distribution, extent and physical condition of the habitats as well as the condition of the associated benthic community (Borja et al., 2013). While in HD the assessment of the community condition focuses on full inventory of the presence of representative/characteristic species at specific sites, MSFD requests a broader view on the assessment scales and the parameters used, including the estimates of alteration of key functions of the habitats. As the recently discussed Commission decision focuses on the assessment of spatial changes of habitats (area loss and extent of adverse effects, Com Dec XXX, under public commitment – available at https://ec.europa.eu/info/law/better-regulation/share-your-views_en), the integration of techniques covering larger areas is of increasing importance. However, sessile hard-bottom communities are not easily quantifiable (Pagola-Carte et al., 2002) and monitoring has proven to be more difficult than for communities inhabiting unconsolidated sediments (Van Rein et al., 2009). Monitoring protocols regarding hard substrata assemblages vary considerably worldwide and many nationally standardized methods were developed within tropical latitudes, especially for surveying coral reefs (Great Barrier Reef Marine Park Authority, 2015; NOAA Coral Program, 2014; Van Rein et al., 2009). In temperate latitudes and the aphotic zone, these monitoring programs are often inapplicable, resulting in the fact that due to a lack of guidelines sampling gear and strategies are frequently borrowed from well-studied soft sediment habitats, which in turn show major drawbacks on consolidated substrata.

Originally designed for sampling soft sediment habitats, on coarser-grained sediments standard physical sampling by grabs and box corers do not yield same intact, repeatable and quantitative records due to varying penetration depth and inappropriate closure of the gear (Eleftheriou and Moore, 2013; Jamieson et al., 2013; Rees, 2009). On solid surfaces like bedrock and boulders, grabs operate at low sampling efficiency or fail to operate at all (Rees, 2009). The deployment of demersal trawls or dredges in monitoring surveys can provide lacking information on epibenthic macro- and megafauna and may sample important elements of the benthic environment on large spatial scale (Eleftheriou and Moore, 2013; Jørgensen et al., 2011). On hard-bottom habitats, dredges are able to break off pieces of rock and scrap off organisms from hard surface (Nalwalk et al., 1962; Rees, 2009). However, uncertainty of area sampled and efficiency of capture diminish and outbalance interpretability as samples can often only be treated qualitatively (Eleftheriou and Moore, 2013; Jørgensen et al., 2011). Dredging is unsuitable on rough terrain like boulder fields and is intrinsically disruptive to the seabed (Rees, 2009). In regard to annual or periodically repeated environmental monitoring, destruction and habitat loss can be severe and extensive and it would be misleading to return to the same location for repetitive sampling. The only non-remote technique used regularly for status monitoring of benthic hard-bottom habitats including tropical coral reef, is SCUBA diving. Various survey methods exist, notifying the presence or quantifying the abundance and coverage of epibenthic taxa along a transect or within a quadrat (Kautsky, 2013). However, scientific diving in temperate seas with cold water, ocean swell and high turbidity is difficult and technically often restricted to approximately 30 m depth. Visual description along a transect or within a frame as widely used in coral reef surveys have the disadvantage of requiring reasonable time underwater for the taxonomically well trained divers. Under field condition in temperate waters, quantitative sampling of organisms within a frame by means of physical collection into the net-bag is therefore needed when assessing biodiversity (Kautsky, 2013).

The choice of methodology has strong implication for the effectiveness of monitoring efforts (Smale et al., 2012) in terms of quality of data and ecological metrics derived (e.g. presence/absence, abundance, biomass, cover), level of precision and costs in terms of time spend in the field and for analysis (Bennett et al., 2016; Dumas et al., 2009). Therefore, researchers and resource managers should carefully follow up recent technological advancements that could increase data completeness and cost efficiency (Bennett et al., 2016). Especially for repeated monitoring activities when fragile biota and/or long-lived taxa on hard substrata are in focus the damage and loss effects of sampling should always be considered. ‘A picture is worth a thousand worms’ concept, highlighted by Solan et al., 2003 within the context of well-established but necessarily destructive sampling practice in benthic ecology, is still relevant and to be reviewed for major hard-bottom monitoring programs 13 years later. Benthic imagery can be collected by unmanned platforms and enables surveys of large area and great depths even in regions of complex topography with fragile species (Jamieson et al., 2013; Perkins et al., 2016). Equipped with downward facing video and still cameras, hovering slowly across the seafloor habitats (Jamieson et al., 2013), these platforms are marginally invasive and create permanent records that allow community studies at exact same location over time for reasonable costs (Dumas et al., 2009; Perkins et al., 2016). Confronted with large quantities of imagery, great progress has been achieved by scientists who endeavored to program tools to describe, analyze and index underwater videos and stills. A series of specialized marine image annotation software have been developed in the last two decades helping to manage imagery data from monitoring activities (Gomes-Pereira et al., 2016). Therefore, high resolution visual documentation may be able to assess abundance of at least large habitat-forming organisms (Buhl-Mortensen et al., 2014) and may yield quantitative information as surface cover estimates. Biodiversity and distribution of large, conspicuous organisms could be assessed by seafloor imaging on atolls (Longo et al., 2015), mesophotic reefs (Meirelles et al., 2015), artificial hard substrata as disposed bombs (Kelley et al., 2015), seamounts (Clark and Bowden, 2015), deep water rocky reefs (Meyer et al., 2014) and deep-sea dropstones (Meyer et al., 2016). Recently, Segelken-Voigt et al. (2016) demonstrated that single groups of organisms, like ascidians, known as indicator for spatial environmental variability could be identified and quantified at water depth from 70 to 770 m by benthic imagery. Appearing to be an appropriate alternative to diver operated visual surveys as well as physical sampling practices, the method is subject to a number of challenges (Howell et al., 2014), in particular the low taxonomic resolution and missing of obscured or cryptic taxa and functional groups (Bennett et al., 2016; Holmes et al., 2013).

In order to integrate hard substrata and their associated macroscopic epibenthic assemblages in EU monitoring programs, it is central to comparatively evaluate the performance, cost effectiveness and disturbance of available methods on hard-bottom habitats in temperate seas. This study should be understood as a precursory method comparison for pending monitoring activities, to understand the relationship of empirical data from physical collection and image-based sampling. The study makes no claims of giving a complete description of the epibenthic communities, their driving factors and pollutants in the studied area. We report findings on the benefits and shortcomings of the use of benthic imagery within the monitoring of epibenthic hard-bottom communities in a NATURA 2000 marine protected area in the southwestern Baltic Sea. Results will help to address the following questions: (1) Is seafloor imaging able to detect important functional groups? (2) How much of the total species richness is captured by the method? What is the potential loss in taxonomic resolution? (3) How well new information generated corresponds to the needs of monitoring programs demanded by EU MSFD and HD? (4) Can current monitoring practices be revised to the extent that habitat disturbance is reduced and pending monitoring requirements are fulfilled?

2. Materials and methods

2.1. Study area

The central part of the “Fehmarn Belt” marine protected area (EU-Code: DE 1332–301) in the south western Baltic Sea was selected for the